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Wind tunnel simulation experiment on the erodibility of the fixed aeolian sandy soil by wind

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Introduction

Approximately 20% of the world's arid zones are covered by sand seas, sand sheet, and by dune fields (Pye and Tsoar, 1991). In the case of China, aeolian sandy soils are widely distributed in the arid regions of northwest China, humid regions of southeast China and the Tibet Plateau. The fixed aeolian sandy soils cover extensive areas of the southeastern edge of the Tengger Desert, where sand dunes bordering the railway have been vegetated by means of straw checkerboard barriers since 1956. The fixed aeolian sandy soil has been effective in stabilizing soil surface and preventing desert railway from migrating sand dune (Li et al., 2001). During the past 44 years, an 8-59 mm thick microbiotic crust has been formed in the surface of the fixed aeolian sandy soil. In order to get a better understanding of the effectiveness of the fixed aeolian sandy soils in controlling soil erosion by wind and to identify its certain underlying principles for its strong resistance against wind erosion, the objectives of this paper were to investigate the natural wind erodibility of the fixed sandy soil and the accelerating effect of human disturbance on wind erosion by means of wind tunnel simulation and discuss the effects of microbiotic crusts and vegetation covers on wind erosion.

Materials and methods

The wind erosion experiment was conducted in a push-type wind tunnel of the Laboratory of Blown Sand Physics and Desert Environments at the Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences. The undisturbed fixed sandy soil samples were taken from Shapotou at the southeastern edge of the Tengger Desert in the arid region of north China. The soil sampling and wind tunnel experiment were described by Li et al. in detail (2001). First, three soil samples subjected to free-stream wind velocity from 10 to 26 m s^{-1}, with equal intervals of 2 m s^{-1} to measure natural erodibility by wind. The tests lasted from 2 to 15 min depending upon wind speed. Then the soil samples in the tray were " plowed" by a hand chisel to a depth of 10 cm, and larger clod were broken into small pieces, which represented cultivation. The "plowed" soils also subjected to the above mentioned wind velocity. Vegetations in other three soil samples were clipped to a cover density of 30, 15 and 0% to simulate the effects of vegetation cover on soil erosion. Then surface crust was broken with the point-grid method to the percentage of 20, 40, 60, 80 and 100% to simulate the effects of crust on soil erosion. The soil samples were blown under the wind velocity of 10, 18, 26 m s^{-1} for each treatment.

Results and discussions

The experimental results indicated that there was a close exponential relationship between wind velocity and soil erosion rate (Figure 1). In the case of the undisturbed (natural) fixed sandy soil, there was virtually no wind erosion at wind speeds less than 8 m s^{-1}, while wind erosion began at velocity 6 m s^{-1} for the cultivated sandy soil. Erosion rates of the cultivated treatments were 3.6, 51.8, 102.6, 311.6, 426.7 times of the undisturbed fixed sandy soil at the wind velocity of 10, 16, 20, 24, 26 m s^{-1}, respectively. The soil loss rate (SLR = soil loss from undisturbed soil/ soil loss from cultivated soil) versus wind velocity is presented in Figure 2, indicating that the relationship follows negative exponential function. The ratio between total soil loss from the undisturbed soil and the cultivated soil was about 0.004. The results suggest that cultivation or trample can substantially accelerate erodibility of the fixed sandy soil by wind.

Soil erodibility by wind reflects the fragility of soils suffering from wind deflation and abrasion. The natural wind erodibility of the fixed sandy soil is affected appreciably by surface vegetation and crust. Figure 3 shows that wind erosion rate increases with decreasing vegetation cover at the wind velocity of 10, 18 and 26 m s-^{1}, suggesting that vegetation is one of the factors responsible for the natural wind erodibility of the fixed sandy soil, which would reduce soil erosion by wind.

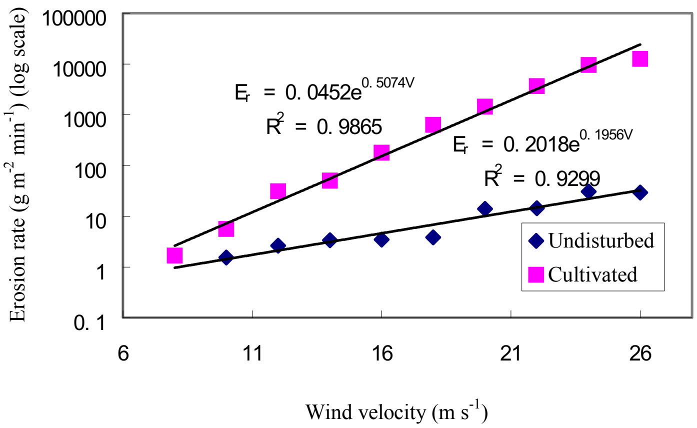

Figure 1 Relationship between wind erosion rate and wind velocity for the undisturbed fixed sandy soil and cultivated fixed sandy soil

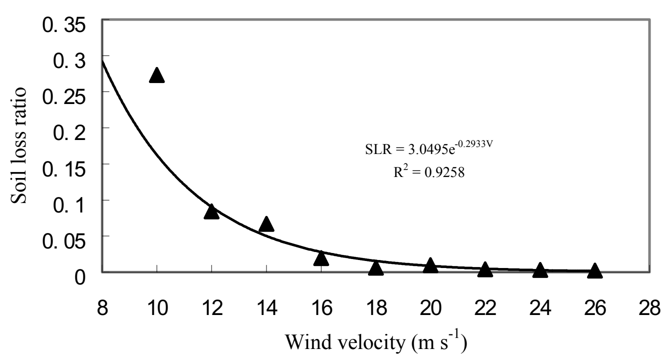

Figure 2 The relationship between soil loss ration (soil loss from undisturbed soil/ soil loss from cultivated soil) and wind velocity

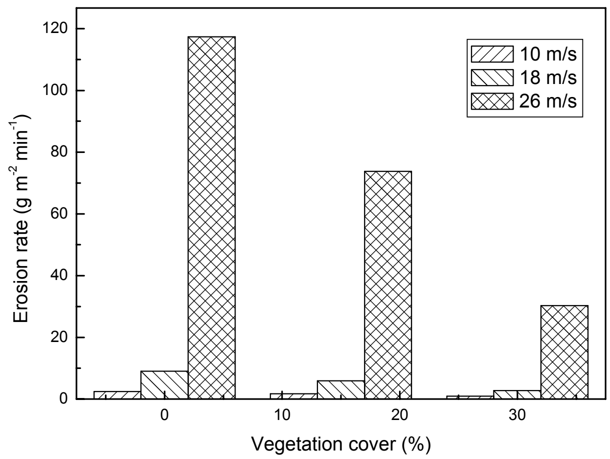

Figure 3 Effect of vegetation cover on wind erosion for the fixed sandy soil

The importance of microbiotic crusts for surface stabilization and in particular for dune stabilization has long been noted (Belnap and Gillette, 1997). Biological soil crust, which are formed by communities of several types of microphytes including mosses, lichens, fungi, green and blue-green algae as well as bacteria, are a common and widespread phenomenon in sandy soils. By creating a multi-layered net of sheaths and filaments and by exopolysaccharide and slime excretion, the filamentous cyanobacteria, together with other microorganisms, bind the upper surface, forming an intricate webbing of fibers in the soil. In this way, loose soil particles are joined together, and otherwise unstable and highly erosion-prone surfaces become resistant to both wind and water (Belnap and Gardner, 1993). Figure 4 indicates that surface microbiotic crusts on fixed sandy soils have great effects on wind erosion rates, and wind erosion increases with decreasing percent of crust cover, following negative exponential functions. Wind erosion rate for sandy soil with 0% crust cover was about 1.8, 9.5 and 9.4 times of the soil with 100% crust cover at the wind velocity of 8, 18 and 26 m s^{-1} respectively. The results demonstrate that soil crust has a high effectiveness in controlling wind erosion.

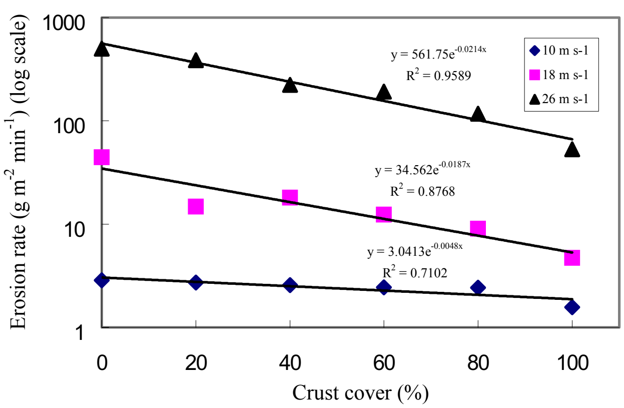

Figure 4 Effect of soil crust cover on wind erosion rate for fixed sandy soils

Grain size distribution of the eroded soil (Table 1) indicated that the highest percentage of particles occurred in the range 0.1-0.25 mm for all the treatments The grain size distribution showed a higher percentage of particles in the range >1.0 mm and a lower percentage in the range <0.05 mm for the cultivated sandy soil than for the undisturbed fixed sandy soil (Table 1). Also, Table 1 indicates that the contents of >0.25 mm fractions increase with the increase of wind velocity for the cultivated sandy soil, while <0.05 mm fraction shows an opposite trend. There are no obvious changes of size distribution for the undisturbed fixed sandy soil.

Table 1. Grain size distribution of eroded soil samples at the wind velocity of 10 m s^{-1}, 18 m s^{-1} and 26 m s^{-1} from the wind tunnel experiments

Velocity	Treatments	Percent distribution of soil grains (mm)						
		>2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.1	0.1-0.05	<0.05
10 m s^{-1}	Undisturbed	0	0	2.23	5.95	51.30	23.79	16.73
	Cultivated	0.52	0.71	1.43	2.87	54.04	25.16	15.25
18 m s^{-1}	Undisturbed	0	0	1.11	3.33	58.89	24.44	12.22
	Cultivated	0.3	0.69	1.20	5.35	74.63	9.52	8.30
26 m s^{-1}	Undisturbed	0.46	0.37	1.11	3.79	56.44	24.75	13.07
	Cultivated	3.11	1.65	1.72	8.13	68.87	11.76	4.77

Conclusions

The main results of the experiment can be summarized as follows:

(1) Human disturbance such as cultivation or trample can accelerate the erodibility of the fixed sandy soil. The ratio between total soil loss from the undisturbed soil and the cultivated soil was about 0.004.

(2) Surface vegetation and microbiotic crust are the main factors responsible for the natural wind erodibility of the fixed sandy soil. Wind erosion rate increases with decreasing percent of the vegetation and crust cover.

(3) The grain size distribution showed a higher percentage of particles in the range >1.0 mm and a lower percentage in the range <0.05 mm for the cultivated sandy soil than for the undisturbed fixed sandy soil.

Acknowledgments

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